TUSTUMENA LAKE PROJECT REPORT: SOCKEYE SALMON INVESTIGATIONS (FALL 1992-1993)

by

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ABSTRACT

The 1992 and 1993 adult sockeye salmon *Oncorhynchus nerka* escapements into Tustumena Lake based on sonar counts in the Kasilof River were estimated at 184,178 and 149,939, respectively. Weir counts of adult sockeye salmon entering Bear and Glacier Flats Creeks in 1992 were 44,100 and 9,144, respectively. Peak spawner surveys conducted during August 1992 on 5 other tributary streams of Tustumena Lake totaled 28,813 sockeye salmon; thus, 82,057 (45%) of the estimated sockeye salmon escapement were accounted for by weir counts and peak spawner surveys. The weir count for Bear Creek in 1993 totaled 45,125 adult sockeye salmon. No surveys were conducted on the other spawning tributaries of Tustumena Lake in 1993. The hatchery contribution of adult sockeye salmon in the escapement for 1992 was 21,070 (11.4% contribution rate) and for 1993 was 4,348 (2.9% contribution rate). An estimated 121,264 and 18,851 hatchery-produced fish contributed to the total Tustumena Lake sockeye salmon returns for 1992 and 1993, respectively.

A total of 19.4 and 14.3 million sockeye salmon juveniles were estimated in Tustumena Lake through hydroacoustic/townet surveys conducted during September 1992 and 1993, respectively. The age composition of collected sockeye salmon fry for 1992 was 93.9% age-0 and 6.1% age-1, and for 1993 was 90.1% age-0 and 9.9% age-1. The mean size of age-0 fry in 1992 was 59 mm and 2.0 g, and in 1993 was 63 mm and 2.9 g. The mean weight of age-0 fry in 1993 was considerably larger than any other year since 1980.

The estimated number of sockeye salmon smolts that emigrated Tustumena Lake in the spring of 1993 was 9.0 million. The smolt population was comprised of 7.2 million (79.7%) age-1 smolts and 1.8 million (20.3%) age-2 smolts. The mean size of age-1 smolts was 69 mm and 2.6 g. In 1993, the age-1 smolt size was similar to the mean for 1980-1992. The number of hatchery-produced smolts in 1993 was estimated at 516,000, or 5.7% of the total emigration.

Limnological surveys in 1993 indicated a higher seasonal mean chlorophyll *a* concentration, that probably was a result of mild weather in 1993. Mild weather conditions (sunny days, warm temperatures) results in a higher similation of nutrients such as total phosphorus into phytoplankton growth. This condition most likely contributed to the higher biomass of *Diaptomus* and *Cyclops* in 1993 and the relatively large fall fry.

KEY WORDS: sockeye, fry stocking, smolt and adult production, glacial lake, limnology

INTRODUCTION

The Tustumena Lake sockeye salmon *Oncorhynchus nerka* investigation project was initiated in 1981 to assess the juvenile and adult sockeye salmon populations relative to the effects of stocking hatchery fry. The primary goals of this project are to determine in-lake factors affecting productivity, and to assess the stocking program relative to averting negative impacts to the natural production of sockeye salmon.

Initially, the working hypothesis of sockeye salmon production in Tustumena Lake was that this system operated in a typical density-dependent fashion, where the variability in smolt production (juvenile-rearing success) is related to fluctuations in freshwater trophic levels (Foerster 1944; Johnson 1965; Brocksen et al. 1970; Koenings and Burkett 1987; Kyle et al. 1988). However, if juvenile fish density is not sufficient to challenge the limnetic forage base, and trophic-level responses become uncoupled from fish density, observed trophic changes may be correlated to environmental variables (density-independent). In Tustumena Lake, Kyle (1992) reported that trophic-level responses were inconsistent with unconditional density-dependent sockeye salmon production. A preliminary analysis in Tustumena Lake suggests that sockeye salmon production is density-independent, as environmentally dependent variables were responsible for a majority of the annual variation in the production of wild age-1 smolts (Koenings et al. 1988).

This report summarizes fisheries and limnological data collected during the period 1 July 1992 through 20 October 1993. This information is used to assess the hatchery stocking project through monitoring juvenile and adult sockeye salmon production and changes in limnological parameters in Tustumena Lake. Sockeye salmon investigations in Tustumena Lake have been on-going since 1980. In 1974 sockeye salmon eggs were first taken from Glacier Flats Creek. Since then, sockeye salmon eggs have been taken each year from Glacier Flats Creek, Bear Creek or both, and fry have been stocked in Tustumena Lake at levels ranging from 6-17 million. Previous years of information on this project are summarized by Kyle (1992), and federal-aid (Anadromous Fish Conservation) annual reports are available for 1987-1992.

Study Site Description

Tustumena Lake is located on the Kenai Peninsula (60° 10' N, 150° 55' W). This lake has a surface area of 294.5 km^2 (73,942 acres), a mean and maximum depth of 24 m and 320 m, and is approximately 40-km long and 8-km wide (Figure 1). Tustumena Lake is fed by clearwater as well as glacial creeks that originate in the Harding Icefield. The lake outlet (Kasilof River) drains into Cook Inlet over a watershed area of 1,376 km^2. Tustumena Lake lies within the Kenai National Wildlife Refuge, and therefore, project activities are regulated under a special use permit issued each year to the Alaska Department of Fish and Game (ADF&G) by the United States Fish and Wildlife Service (FWS).

All 5 species of Pacific salmon are found in this lake system, though sockeye salmon predominate. Sockeye salmon escapements have been estimated in the Kasilof River by sonar since 1968. Annual escapements have ranged from a low of 40,000 in 1973 to a high of 505,000 in 1985 (King and Tarbox 1991). The estimated commercial fishing exploitation rate of sockeye salmon bound for the Kasilof River has ranged from 50% to 85%. Sockeye salmon returning to the Tustumena Lake system are a major contributor to the total Cook Inlet sockeye salmon harvest.

METHODS

Adult Escapement Surveys and Hatchery Contribution

Adult sockeye salmon were enumerated by weirs located on Bear Creek (1992 and 1993) and Glacier Flats Creek (1992 only). Ground surveys were preformed upstream of the weir at time of installation, and downstream of the weir upon removal. In 1992, spawning escapement surveys were also conducted three times during August for peak escapement counts on Moose, Clear, Crystal, and Seepage creeks. In addition, Nikolai Creek was surveyed once in 1992 by helicopter using a designated area that was surveyed by foot and from the air to calibrate the total aerial count. In 1993, sockeye salmon were counted during the egg-take operation at Bear Creek; however, no escapement surveys were conducted on the other creeks.

The contribution of hatchery-produced fish to the Tustumena Lake sockeye salmon escapements in 1992 and 1993 was estimated from respective hatchery smolt data and the corresponding return of adults by age class. The adult sockeye salmon age composition is determined from data collected at the Kasilof River sonar/fishwheel site, operated each year by ADF&G. As not all hatchery released fingerlings were marked, the total number of hatchery-produced sockeye salmon in the escapement was computed from: 1) the corresponding years of release, 2) the number of fingerlings released, and 3) the number of fingerlings marked. The contribution rate of hatchery-produced sockeye salmon in the total return (escapement and harvest) was determined by making the assumption that the same ratio of hatchery-to-wild fish estimated in the escapement also occurred in the commercial, personal-use and sport catches of Tustumena Lake sockeye salmon.

Hydroacoustic/Townet Surveys

Hydroacoustic surveys were conducted on 22 September in 1992 and 1993 to estimate the number and distribution of sockeye salmon fingerlings rearing in Tustumena Lake. Hydroacoustic surveys were comprised of recording data along 9 transects perpendicular to the longitudinal axis of the lake (Figure 2). The lake was divided into 3 equal areas, and 3 transects per area were selected randomly. Recording of down-looking acoustic data along the transects was done at night because juvenile sockeye salmon in this lake are somewhat more dispersed during darkness. In 1992, the transects were conducted at 2 m/sec, and in 1993 the transect speed was increased to 2.5 m/sec. Survey speeds were checked periodically during each transect with a Marsh McBirney model-201 portable water current meter. An Azure loran navigation receiver was used to maintain transect course. A BioSonics model-105 echosounder system with a 6/15° dual-beam transducer was used for the survey. Fish signals were recorded electronically using a Sony digital audio tape (DAT) recording system and on paper using a BioSonics model-115 chart recorder.

Analysis of the recorded hydroacoustic tapes was conducted by Dr. Richard Thorne of BioSonics, Inc., under a State of Alaska contract. Fish densities were low enough during both surveys to allow the use of echo-counting techniques (Thorne 1983) for the population estimate. The number of echoes from fish targets were counted in 10-min increments along the 9 transects and in 5 depth intervals. Sampling volumes were estimated by the duration-in-beam technique (Nunnallee and Mathisen 1972; Nunnallee 1980; Thorne 1988). For each depth interval and 10-min increment, fish densities (no./m^3) were summed to determine the total areal fish density (no./m^2) for each transect. Mean fish densities were weighted by time, since end-of-transect increments were usually less than 10 min. A mean areal fish density and an associated variance was computed from the 3 transects per area (Kyle 1990). The total population estimate was obtained by multiplying the lake area representing each transect by the mean transect fish density, and summing all transect population estimates. Transect variances were summed and a 95% confidence interval for the total fish population estimate was calculated.

Townetting was conducted in conjunction with the hydroacoustic surveys to determine species of acoustically-counted fish, and to determine age and size of juvenile sockeye salmon. Townetting procedures consisted of using a 3 x 3-m net pulled at a speed of approximately 1.0-1.25 m/sec. As the fish in Tustumena Lake are located relatively near the surface during both night and day, surface net tows were conducted during the day following each survey. In 1992, a portion of the fry (140) were sampled fresh and the remaining fry (183) were preserved in 95% ethanol for sampling at a later date. The ethanol-preserved weights and lengths were corrected to live weight based on the following: preserved weight (g) times 1.17 + 0.23; and preserved length (mm) + 1 (Stan Carlson, ADF&G, Soldotna, personal communication). In 1993, all captured juvenile sockeye salmon were preserved in a 10%-buffered formalin solution for 6 weeks before being subsampled and measured for individual snout-to-fork lengths (nearest 1.0 mm) and weights (nearest 0.1 g). A scale smear was taken from each fish in the subsample, and ages were determined with the use of a microfiche reader.

Smolt Enumeration and Sampling

One inclined-plane smolt trap (Kyle 1983) was placed in the Kasilof River on 10 May and operated through 30 June 1993. The trap measured 1.5 m wide by 1 m in height, and was 3.8 m long. Each day, captured smolts were either individually enumerated (<7,000 per day) and released, or when the daily smolt numbers exceeded 7,000, the number of smolts were estimated using a biomassing technique. This biomassing procedure entailed weighing 100 individual sockeye salmon smolts every other day to obtain a mean smolt weight, which was divided by the total weight of the sockeye salmon smolts caught in each trap to estimate the number of smolts.

The population estimate of the total number of sockeye salmon smolts migrating from Tustumena Lake was made using weekly trap efficiencies determined through a mark-and-recapture procedure (Rawson 1984). During each week in May, 700 sockeye salmon smolts were dyed and released upstream of the traps to estimate trap efficiency. In June, during the peak of the migration, the number of dyed and released smolts was increased to 900. The dyed smolts were placed in an aerated transport tank containing a dye solution (1 g of Bismarck Brown Y dye to 30 liters of water), and remained in the dye for 30 minutes during transport to the release location, approximately 2 km upstream. The dyed smolts were placed in a live box in the river to recover and assess handling mortality prior to release. Dyed smolts recaptured in the trap were enumerated and released. Weekly migrations were estimated from the recovery of stained smolts to determine trap catch efficiency. The percentage of the total migration comprising age-1 and age-2 smolts was estimated for each weekly period using scales obtained from samples collected that week. This percentage was then applied to the estimated total smolt migration for the weekly period to obtain estimates of the number of migrating smolts for each age class (Flagg et al. 1984).

The number of hatchery-produced sockeye salmon smolts migrating each year was estimated from the proportion of marked-to-unmarked smolts recovered during sampling by weekly periods (up to 4,500 smolts per day were observed for missing ventral fins), and the expansion of the estimated marked smolts by the percentage marked for that respective release year (Reed 1981). In addition, the number of hatchery smolts produced each year was adjusted by a differential mark-mortality factor of 1.5 after Flagg et al. (1987).

Every other day through the peak of the smolt emigration, a random sample of 50 sockeye salmon smolts was sampled for age and size. After the emigration peaked, the smolts were sampled twice weekly. The smolts were anesthetized in a solution of MS-222 and measured for snout-to-fork length (nearest millimeter) and weight (nearest 0.1 g). A scale smear was taken from each of the sampled smolts and read with the use of a microfiche reader to determine age.

Limnological Surveys

Limnology sampling in Tustumena Lake was conducted once every 3 weeks during the ice-free period at three stations characterizing the three lake basins (Figure 1). Chemical and biological samples were analyzed according to standard limnology procedures (Koenings et al. 1987). Dissolved oxygen (DO) and temperature profiles (taken at 1 m intervals from the surface to 5 m, then at 5 m intervals to 50 m or the bottom at Station A) were recorded at each station using a Yellow Springs, Inc. model-57 temperature/DO meter. Water samples for nutrient and chemical analysis were taken from depths of 1 m and 50 m at Stations B and C, and 1 m and 25 m at Station A. The 1% incident light level (euphotic zone depth) was measured using a Protomatic submersible photometer. Zooplankton were collected with a 0.5-m diameter zooplankton net of 153 μm mesh. Duplicate tows from each station were taken and preserved in a 10%-buffered formalin solution for species identification, enumeration, and sizing (Koenings et al. 1987). Two additional zooplankton stations were sampled on each sample trip; one midway between stations A and B, and one midway between Stations B and C.

RESULTS AND DISCUSSION

Adult Escapement Surveys and Hatchery Contribution

The escapement (weir count) for 1992 into Bear Creek (one of the enhanced tributaries), including estimates of sockeye salmon bound for this creek (i.e., counts below the weir near the creek mouth), was 44,100 (Table 1). The weir and peak salmon counts for the 7 major tributaries totaled 82,057 sockeye salmon in 1992, and thus accounted for 45% of the estimated 184,178 sonar-enumerated sockeye salmon escapement. Of all the creeks surveyed in 1992, the proportion of the sockeye salmon escapement that entered Glacier Flats Creek varied the most; 11.1% of the total escapement counts compared to the 1984-1991 mean of 30.4%. This may be due to the low water levels observed in Glacier Flats Creek in 1992 and the subsequent loss of spawning habitat. In 1993, a total of 45,125 sockeye salmon were counted through the Bear Creek weir during the egg-take operation.

In 1992 and 1993, the estimated number (and percentage) of hatchery fish in the total escapement was 21,070 (11.4%) and 4,348 (2.9%) respectively, which was lower than the mean for 1984-1991 (Table 2). During 1984-1991, the average number of hatchery fish in the escapement was an estimated 78,636, which represented 31.4% of the average Kasilof River sonar count. The relatively lower returns of hatchery-produced sockeye salmon in 1992 and 1993 resulted from a lower stocking level (beginning in 1988) and stress-related mortality (presumably high temperature and low oxygen levels) during the fry transports of 1989 and 1990.

The estimated commercial harvest of Tustumena Lake sockeye salmon was 869,407 in 1992 and 493,098 in 1993 (Randall Davis, ADF&G, Soldotna, personal communication). Using the hatchery contribution rate of 11.4% in 1992 and 2.9% in 1993, an estimated 99,460 and 14,300 hatchery-produced sockeye salmon were harvested in the commercial fishery, respectively (Table 2). In addition, an estimated 734 and 203 hatchery-produced sockeye salmon in 1992 and 1993 were caught in the personal-use and sport fisheries. Thus, of the total returns of sockeye salmon to Tustumena Lake in 1992 and 1993, an estimated 121,264 and 18,851 fish were hatchery-produced.

Hydroacoustic/Townet Surveys

An estimated 19.4 ± 4.6 million juvenile sockeye salmon fry were rearing in Tustumena Lake during late September 1992 (Table 3). The highest fish density (156/m^2) was observed in the southern half of transect 1 (Figure 2). Transect 1 usually has the lowest fish densities in the fall, however; in 1992 this transect had the highest fish densities, particularly along the southeast side of the lake where Tustumena Glacier drains into the lake.

Analysis of data collected during the September 1993 hydroacoustic survey revealed a problem with the DAT recorder, despite the appearance of normal recording of data during the survey. Data from transects 1-5 were not useable for analysis; however, data for transects 6-9, that were collected with a different DAT recorder, were analyzed. A preliminary estimate of 14.3 million fish in 1993 was made based on comparing fish densities for transects 6-9 with the 1992 survey and extrapolating the area of the lake not surveyed in 1993 due to equipment failure (Table 4). No confidence intervals were computed for the fall 1993 estimate of rearing fry because of the missing information. The highest fish density ($120/m^2$) in 1993 was observed in the middle of transect 6.

Townetting in the fall of 1992 resulted in a catch of 344 juvenile sockeye salmon for age and size data (Table 5). Age-0 fish comprised 93.9% of the total number of juvenile sockeye salmon caught, and averaged 58 mm and 2.0 g in size (Table 6). The remaining sockeye salmon juveniles were age-1 fish which averaged 80 mm and 4.6 g in size. The mean size of fry for both age classes were larger than the 1980-1991 mean; however, in previous years the size was based on formalin-preserved fish. The townetting conducted after the fall survey in 1993 resulted in a total catch of 463 juvenile sockeye salmon, of which 417 (90.1%) and 46 (9.9%) were age-0 fry and age-1 fry, respectively (Table 5). Fry in 1993 were preserved in formalin as was the case in all previous years except 1992. The age-0 fry in 1993 averaged 63 mm and 2.9 g, and the age-1 fry averaged 81 mm and 6.2 g (Table 6). The sizes of fall fry in 1992 and particularly the weight of fry in 1993 were substantially larger than other years and for the 1980-1991 mean (Table 6). In addition, the percentages of age-0 fry were greater than 90% in 1992 and 1993 compared to the 1980-1991 mean of 80%. The presence of a higher percentage of age-0 fry in the fall reflect relatively good summer growing conditions and the likelihood of relatively higher overwintering survival.

Smolt Enumeration and Sampling

In 1993, an estimated 9,022,271 ± 2,468,526 sockeye salmon smolts emigrated Tustumena Lake during 11 May-30 June (Table 7). During the course of the migration two migrational peaks occurred; a large peak during 28-30 May when 2.3 million smolts emigrated, and a second peak during 7-9 June (Figure 3). The 1993 migration consisted of 80% age-1 and 20% age-2 smolts that averaged 69 mm and 2.6 g and 82 mm and 5.2 g, respectively (Table 8). The mean size of smolts in 1993 was similar to the mean during 1981-1992, although there was a higher percentage (16% higher) of age-1 smolts in 1993 compared to the mean during 1981-1992 (Table 8). Based on the weekly age compositions, an estimated 7,189,100 of the total 1993 smolt migration comprised age-1 smolts and 1,833,200 comprised age-2 smolts (Table 9). Finally, a total of 516,000 hatchery-produced smolts (5.7% of the total) emigrated Tustumena Lake in 1993, which was similar to 1991 and 1992 when 4.3% and 4.5% of the smolts were hatchery-produced. In 1993, of the hatchery-produced smolts, the majority (456,000) were age-1 (Table 10).

Limnological Surveys

Eight limnological surveys were conducted on Tustumena Lake during both 1992 and 1993. In 1992 and 1993 seasonal mean epilimnetic (1 m) concentrations of corrected total phosphorous (CTP) and ammonia were lower at all three stations than for the station means during 1980-1991 (Table 11). Total nitrogen (Kjeldahl nitrogen plus nitrate + nitrite) was similar for both years at the 3 stations compared to the 1980-1991 means, but because of lower CTP values in 1992 and 1993, the atomic ratio of total nitrogen (TN) to CTP was slightly higher than the means for both years at all stations. In addition, seasonal mean chlorophyll *a* concentrations in 1993 were higher (except at Station C) which could reflect lower grazing by zooplankton, good environmental conditions (e.g., sunlight and temperature), or a combination of the two. In 1992 and more dramatically in 1993, weather conditions were relatively mild that resulted in many sunny days. These conditions result in a higher similation rate of nutrients such as TP into phytoplankton growth and provides more food for zooplankton, the primary source of food for juvenile sockeye salmon.

In 1992, the seasonal mean *Diaptomus* biomass was about 1-2 times higher at both Stations B and C, and the *Cyclops* biomass was similarly higher at all three stations compared to the means for 1980-1991 (Table 11). In 1993, both *Diaptomus* and *Cyclops* mean biomass was much higher (up to 3 times) at the 3 stations compared to the means for 1980-1991. The lower peak chlorophyll *a* concentrations in 1992 and 1993 relative to the mean for 1980-1991 reflect the higher cropping of phytoplankton by zooplankton and supports the observation of higher zooplankton biomass.

Egg Takes and Fry Releases

A total of 13.5 million and 14.2 million sockeye salmon eggs were collected at Bear Creek in 1992 and 1993, respectively (Table 12). Six million sockeye salmon fry were aerial released into Tustumena Lake in both 1992 and 1993. Of the total released into Tustumena Lake for both years, 2.7% were marked by a right-ventral fin clip. The remaining sockeye salmon fry (from Tustumena Lake brood stock) were used for stocking lakes in lower Cook Inlet.

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Table 1. Sockeye salmon escapement counts in major tributaries of Tustumena Lake during 1992.

Creek	Survey Dates			Weir count	Percent of total count	Mean % (1984-1991)
	05 Aug	17-18 Aug	24-25 Aug			
Bear				44,100	53.7%	49.0%
Clear		1,717	1,979		2.4%	1.8%
Crystal		1,105	724		0.9%	0.5%
Glacier Flats		6,399	9,144		11.1%	30.4%
Moose		12,233	15,235		18.6%	10.0%
Nikolai[a]	10,145				12.4%	6.8%
Seepage		349	349		0.4%	1.5%
Total (highest escapement count each creek)				82,057		

[a] Surveyed by helicopter and calibrated ground count on 05 August.

Table 2. Estimated number and percentage of hatchery-produced sockeye salmon in the escapement and total return for Tustumena Lake in 1992 and 1993, and comparison to the mean for 1984-1991.

	1992	1993	Mean 1984-1991
Kasilof River sonar count (escapement)	184,178	149,939	250,807
Bear Creek escapement	44,100	45,125	81,826
Glacier Flats Creek escapement	9,144	N/D	50,441
Other creeks and lake escapement[a]	130,934	N/D	118,540
Estimated number and (%) of hatchery-produced fish	N/D	N/D	30,637
returning to Glacier Flats Creek	N/D	N/D	61.0%
Estimated number and (%) of hatchery-produced fish	N/D	N/D	32,000
returning to Bear Creek	N/D	N/D	38.5%
Estimated number and (%) of hatchery-produced fish	N/D	N/D	25,598
returning to the other creeks	N/D	N/D	13.0%
Estimated number and (%) of hatchery-produced fish	21,070	4,348	78,636
in the escapement	11.4%	2.9%	31.4%
Estimated commercial fishing exploitation rate	82.6%	77.6%	72.4%
Estimated commercial harvest	869,407	493,098	745,102
Estimated number of hatchery-produced fish commercially caught	99,460	14,300	234,637
Estimated number of fish caught in personal-use (dipnet and gillnet) and sport fisheries	6,417	7,000	24,311
Estimated number of hatchery-produced fish in personal-use and sport fisheries	734	203	7,410
Estimated number of hatchery-produced fish in the total return	121,264	18,851	329,684

[a] Represents the difference between Glacier Flats and Bear Creek weir counts and the Kasilof River sonar-enumerated escapement.

Table 3. Densities and population estimates of juvenile fish rearing in Tustumena Lake by transect based on the 22 September 1992 hydroacoustic survey.

Transect	Mean fish density (no./1000 m^2)	Area (X 1000 m^2) transect	Area (X 1000 m^2) total	Weighted mean fish density (no./1000 m^2)	Variance	Fish population	Variance
1	109.25	40,114					
2	72.25	39,973	115,691	88.9	2.45E+02	10,284,382	3.3E+12
3	84.65	35,604					
4	64.43	19,981					
5	61.26	29,121	87,612	49.4	2.22E+02	4,328,680	1.7E+12
6	32.65	38,510					
7	38.86	38,651					
8	56.22	40,223	99,896	47.8	5.95E+01	4,770,269	5.9E+11
9	47.90	21,022					
					Total	19,383,331	5.57E+12
				95% confidence interval		4,626,879	

Table 4. Densities and population estimates of juvenile fish rearing in Tustumena Lake for transects 6-9 on the 22 September 1993 hydroacoustic survey.

Transect	Mean fish density (no./1000 m^2)	Estimated population (transects 6-9)	Estimated lake[a] population
6	61.79		
7	55.25		
8	38.38		
9	15.27	6,547,804	
			14,336,504

[a]Based on comparing densities for transects 6-9 with the 1992 survey and extrapolating the area of the lake not surveyed in 1993 due to equipment failure.

Table 5. Summary of fish caught in net tows during September of 1992 and 1993 in Tustumena Lake.

Date	Tow no.	Tow duration (minutes)	Basin	Depth (m)	Sockeye age-0	Sockeye age-1	Other
			1992[a]				
24 Sept	1	45	C	Surf			
24 Sept	2	45	B	Surf			
24 Sept	3	30	A	Surf			
		Total 120		Total	323	21	11 stickleback
				Percent	93.9	6.1	
			1993				
24 Sept	1	60	C	1	118	19	1 stickleback
24 Sept	2	60	B	1	192	20	
24 Sept	3	60	A	1	107	7	4 stickleback
		Total 180		Total	417	46	
				Percent	90.1	9.9	

[a] In 1992 the sockeye fry were pooled for all tows and basins.

Table 6. Mean size and age composition of juvenile sockeye salmon fry caught in net tows in 1992, and by basin during 1993 in Tustumena Lake, and comparison to the mean for 1980-1991.

	Age 0							Age 1					
	Sample size	Age comp. (%)	Mean length (mm)	S.D.	Mean weight (g)	S.D.		Sample size	Age comp. (%)	Mean length (mm)	S.D.	Mean weight (g)	S.D.
							1992						
	140 [a]		60	4.43	2.0	0.43		20 [a]		80	2.96	4.6	0.56
	183 [b]		58	4.29	2.0	0.41		1 [b]					
Total	323	93.9						21	6.1				
							1993 BASIN A						
	107	93.9	63	6.85	3.0	0.83		7	6.1	81	2.25	5.9	0.44
							BASIN B						
	192	90.6	62	6.57	2.9	0.77		20	9.4	82	3.57	6.3	0.84
							BASIN C						
	118	86.1	63	5.48	2.9	0.72		19	13.9	81	2.48	6.2	0.59
Total	417							46					
Mean 1993		90.1	63	6.68	2.9	0.78			9.9	81	3.03	6.2	0.72
Mean 1980-91		80.0	56		1.9				20.0	76		4.8	

[a]Fry were sampled fresh.

[b]Fry were preserved in 95% ethanol and were corrected to live weights (see Methods).

Table 7. Daily and seasonal population estimates of sockeye salmon smolts emigrating Tutumena Lake, 1993.

Date	No. dyed	No. recov.	Unmarked Fish Caught (x 1000)	Est. Migration	95% Conf. Int. lower	upper
11-May	715	72	0.328	3,298	2,510	4,086
12-May	715	72	0.883	8,878	6,881	10,876
13-May	715	72	0.982	12,689	9,866	15,511
14-May	715	72	1.262	12,689	9,866	15,511
15-May	715	72	2.834	28,495	22,252	34,737
16-May	715	72	6.069	61,021	47,741	74,301
17-May	715	49	10.586	157,406	115,566	199,245
18-May	715	49	5.980	88,918	65,241	112,595
19-May	715	49	11.636	173,018	127,038	218,998
20-May	715	49	16.405	243,930	179,144	308,715
21-May	714	40	22.181	405,275	285,953	524,596
22-May	714	40	8.164	149,166	105,181	193,152
23-May	714	40	8.542	156,073	110,056	202,090
24-May	714	40	19.586	357,861	252,487	463,235
25-May	714	40	9.337	170,599	120,309	220,889
26-May	716	30	9.107	224,295	148,038	300,553
27-May	716	30	11.984	295,153	194,844	395,461
28-May	716	30	24.505	603,531	398,550	808,512
29-May	716	30	44.779	1,102,857	728,391	1,477,323
30-May	716	30	24.656	607,250	401,007	813,493
31-May	900	96	23.904	226,185	183,729	268,641
01-Jun	900	96	28.662	271,207	220,317	322,097
02-Jun	900	96	37.999	359,556	292,115	426,996
03-Jun	900	96	21.767	205,965	167,296	244,633
04-Jun	900	96	16.976	160,631	130,455	190,807
05-Jun	900	96	35.385	334,821	272,015	397,628
06-Jun	900	96	8.998	85,141	69,107	101,175
07-Jun	898	53	31.431	542,003	402,805	681,201
08-Jun	898	53	11.247	193,946	144,061	243,830
09-Jun	898	53	21.461	370,078	274,997	465,159
10-Jun	898	53	7.863	135,591	100,681	170,502
11-Jun	898	53	5.129	88,446	65,633	111,258
12-Jun	898	53	5.463	94,205	69,915	118,496
13-Jun	898	53	5.620	96,912	71,927	121,898
14-Jun	900	63	5.608	81,297	62,112	100,482
15-Jun	900	63	5.067	73,454	56,110	90,799
16-Jun	900	63	5.038	73,034	55,788	90,280
17-Jun	900	63	5.006	72,570	55,433	89,707
18-Jun	900	63	5.150	74,657	57,031	92,284
19-Jun	900	63	4.900	71,033	54,257	87,810
20-Jun	900	63	2.600	37,691	28,740	46,643
21-Jun	901	61	1.899	28,478	21,573	35,383
22-Jun	901	61	3.398	50,957	38,687	63,227
23-Jun	901	61	2.928	43,909	33,321	54,497
24-Jun	901	61	5.896	88,418	67,207	109,629
25-Jun	901	61	5.054	75,791	57,594	93,988
26-Jun	901	61	8.029	120,405	91,560	149,250
27-Jun	901	61	2.622	39,320	29,827	48,813
28-Jun	901	61	1.555	23,319	17,646	28,993
29-Jun	901	61	1.384	20,755	15,693	25,816
30-Jun	901	61	1.340	20,095	15,191	24,999
Totals	6,459	464	569.19	9,022,271	6,553,745	11,490,797

Table 8. Size and age of Tustumena Lake sockeye salmon smolts by sample period, 1993.

Sample period	Sample size	Age class	Percent comp.	Mean length (mm)	S.D.	Mean weight (g)	S.D.
11 - 16 May	83	1	83%	69.2	3.36	2.6	0.40
	17	2	17%	83.1	4.64	4.4	0.86
17 - 23 May	103	1	69%	68.7	3.18	2.6	0.40
	47	2	31%	81.9	4.74	4.2	0.71
24 - 30 May	155	1	78%	67.7	3.64	2.5	0.38
	44	2	22%	81.5	4.63	4.2	0.77
31 May - 06 Jun	145	1	75%	69.4	3.70	2.6	0.04
	49	2	25%	81.9	3.20	4.2	0.58
07 - 13 Jun	140	1	93%	68.5	3.44	2.6	0.39
	10	2	7%	83.8	2.10	4.5	0.38
14 - 20 Jun	46	1	92%	71.3	3.69	3.0	0.46
	4	2	8%	83.3	4.34	4.6	0.63
21 - 30 Jun	83	1	84%	71.5	3.41	3.2	0.44
	16	2	16%	81.2	4.00	4.7	0.70
Weighted mean (1993)		1	80%	68.8	3.54	2.6	0.34
		2	20%	81.9	4.16	4.2	0.69
Mean (1980-1992)		1	64%	69.0		2.7	
		2	36%	83.0		4.5	

Table 9. Population estimate (in thousands) of sockeye salmon smolts emigrating Tustumena Lake by age and sample period, 1993.

Sample period		Age 1 Migration estimate	Age 1 95% Conf. int. lower	Age 1 95% Conf. int. upper	Age 2 Migration estimate	Age 2 95% Conf. int. lower	Age 2 95% Conf. int. upper
11-May	16-May	105.5	90.5	120.4	21.6	6.7	36.5
17-May	23-May	943.3	810.5	1076.1	430.5	297.7	563.2
24-May	30-May	2618.3	2197.2	3039.3	743.3	322.2	1164.3
31-May	6-Jun	1228.4	1108.6	1348.2	415.1	295.4	534.9
7-Jun	13-Jun	1419.8	1238.9	1600.7	101.4	-79.5	282.3
14-Jun	20-Jun	445.0	392.5	497.6	38.7	-13.8	91.2
21-Jun	30-Jun	428.8	379.4	478.2	82.7	33.2	132.1
Total		7189.1	6691.7	7686.5	1833.2	1335.8	2330.6

Table 10. Estimated number of hatchery-produced sockeye salmon smolts emigrating Tustumena Lake, 1993.

Release Location	Year released	Number released (x 1000)	Number marked (x 1000)	Mark type [a]	Number of marks recovered	Est. no. hatchery smolts (x 1000)
		Age 2				
Glacier Flats	1991	80 [b]	80.0	RV	9	1
Glacier Flats	1991	5,920 [c]	75.0	LV	8	59
Subtotal		6,000	155.0			
		Age 1				
Bear Creek	1992	162 [c]	162.0	RV	121	456
Bear Creek	1992	5,900				
Subtotal		6,062	162.0			
Grand total		12,062	317.0			516

[a] RV = right ventral; LV = left ventral.

[b] These fry were transported by helicopter and ground released.

[c] These fry were aerial-dropped.

Table 11. Limnological characteristics within the epilimnion (1 m) of Tustumena Lake during 1992 and 1993, and comparison to the mean for 1980-1991.

Parameter	Station A			Station B			Station C		
	1992	1993	Mean 1980-91	1992	1993	Mean 1980-91	1992	1993	Mean 1980-91
Turbidity (NTU) 1 m	33	40	39	36	43	41	36	43	41
Seasonal mean water temp. (C @ 1 m)	7.4	8.6	9.1	7.3	7.2	8.6	5.8	6.5	6.1
Date of 1 m water at 4 C	5/20	5/20	5/20	5/29	5/30	5/29	6/1	5/30	6/8
Date of heat maximum (C @ 1 m)	8/19	7/30	7/29	7/9	7/30	7/27	7/9	7/30	7/27
Euphotic zone depth (m)	1.3	1.5	1.3	1.5	1.5	1.2	1.2	1.4	1.2
Total phosphorus (P) 1 m (ug/L)	35.1	36.3	46.7	36.3	36.1	49.6	38.8	36.8	50.1
CTP[a] 1 m (ug/L)	3.0	3.1	3.6	3.1	3.1	3.8	3.2	3.1	3.8
Total nitrogen (N) 1 m (ug/L)	149	150	152	144	159	154	154	150	152
Total Kjeldahl (N) 1 m (ug/L)	51.9	59.9	60.0	44.5	64.3	59.6	49.1	54.4	52.6
Ammonia 1 m (ug/L)	2.3	0.8	4.7	2.3	0.4	3.7	1.3	0.7	3.6
Nitrate + Nitrite 1 m (ug/L)	96.6	90.0	92.4	99.5	94.2	94.4	104.9	95.9	98.9
Atomic ratio of TN to CTP	110:1	109:1	94:1	104:1	115:1	91:1	107:1	109:1	89:1
Silicon 1 m (ug/L as Si)	2,140	2,209	2,295	2,094	2,117	2,271	2,071	2,177	2,246
Alkalinity 1 m (mg/L as CaCO3)	13	13	14	12	13	14	12	13	14
pH units (1 m)	6.7	6.8	7.0	6.8	6.8	7.0	6.8	6.8	7.0
Chlorophyll a (1 m, mean)	0.51	0.66	0.54	0.32	0.51	0.41	0.15	0.26	0.41
Chlorophyll a (1 m, peak)	1.57	1.57	3.15	0.86	1.15	2.75	0.50	0.72	4.58
Diaptomus density (No/m^2, mean)	3,427	15,760	7,206	7,678	6,352	8,762	13,224	8,223	4,769
Cyclops density (No/m^2, mean)	31,381	50,337	31,724	31,776	41,450	34,062	39,414	66,640	35,239
Diaptomus biomass (No/m^2, mean)	15	95	33	45	38	28	35	48	20
Cyclops biomass (No/m^2, mean)	87	118	70	79	97	69	103	143	76

[a]Total phosphorus corrected for turbidity and inorganic particulate phosphorus based on CTP = 1.25 = 0.05 TP (Koenings et al. 1987).

Table 12. Egg take and fingerling release information for Tustumena Lake, 1992 and 1993.

Year	Number of eggs taken (x 1000)	Number of fingerlings released (x 1000)[a]	Fingerling mean weight (g)	Number of fingerlings marked (x 1000)	Type of mark[b]	Percent marked
1992	13,500	6,062	0.22	162.0	RV	2.67%
1993	14,200	6,001	0.21	161.5	RV	2.69%

[a]Lower Cook Inlet lakes were stocked with 7.25 million fry in 1992 and with 5.9 million fry in 1993.

[b]RV = right pelvic (ventral) fin clip.

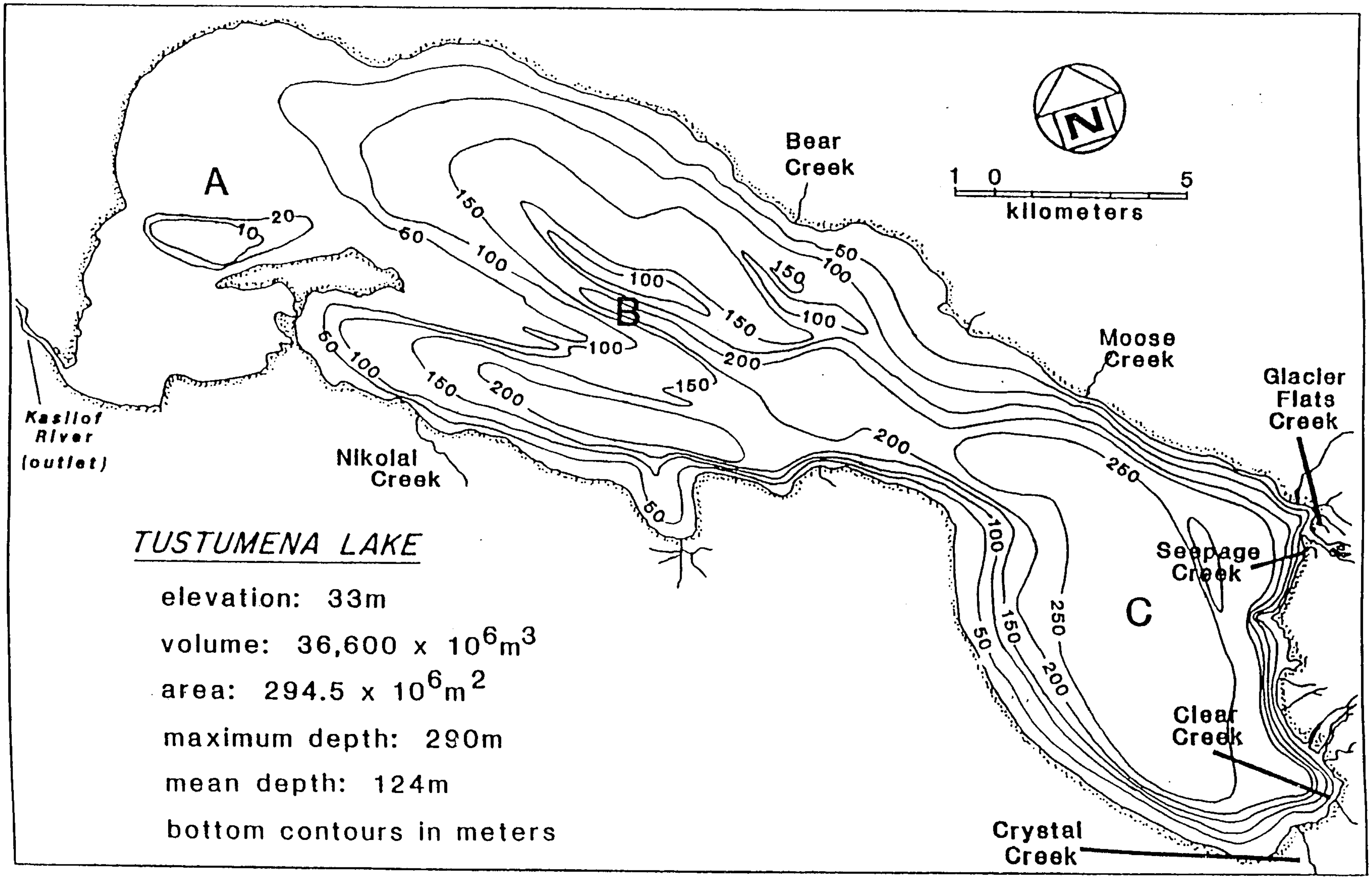

Figure 1. Morphometric map of Tustumena Lake showing the location of limnological sample stations (A-C), and the seven major salmon-producing tributaries.

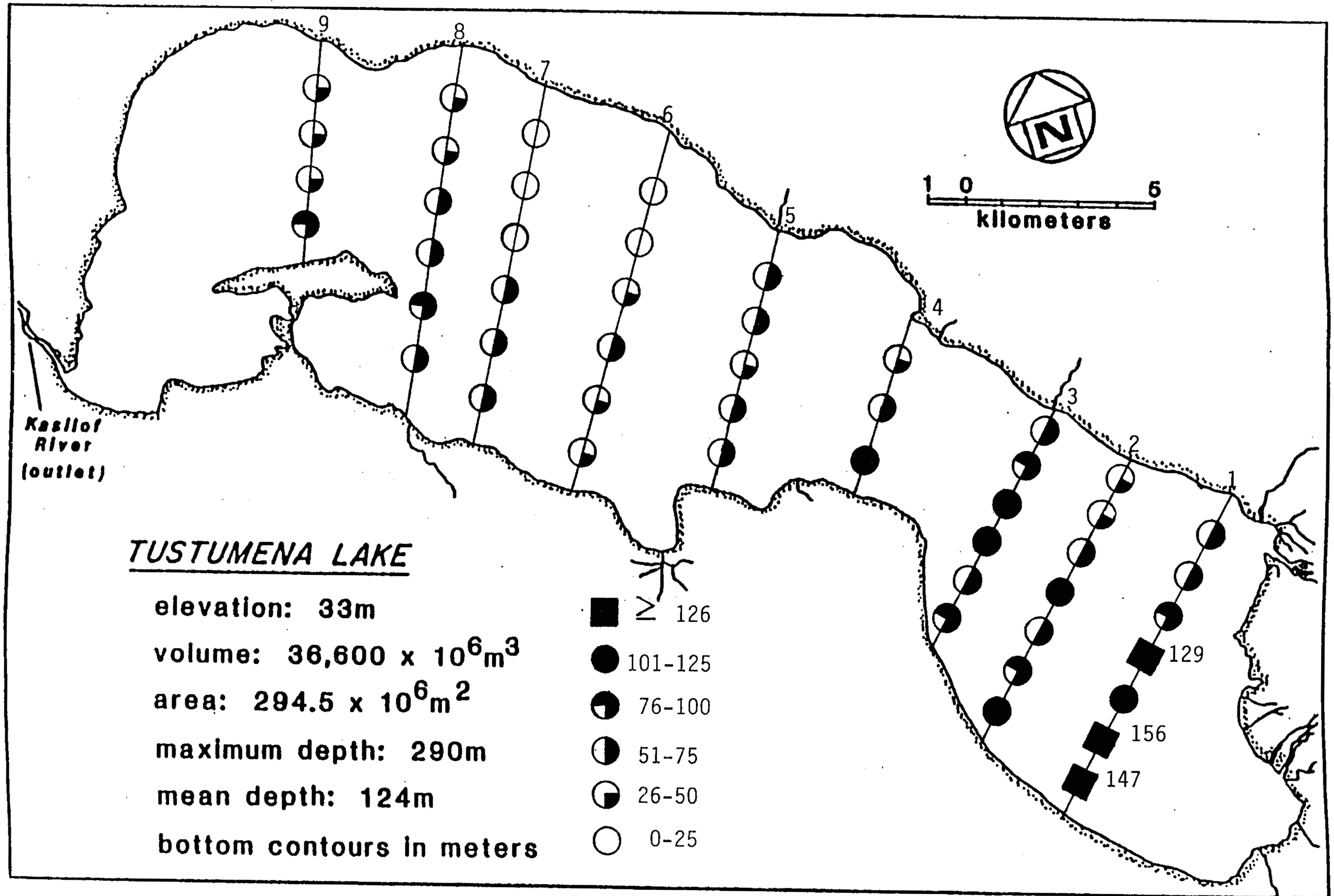

Figure 2. Map of Tustumena Lake showing the nine transects used during the 1992 and 1993 hydroacoustic surveys and distribution of juvenile sockeye salmon density (no./1000 m^2) for the 22 September 1992 hydroacoustic survey.

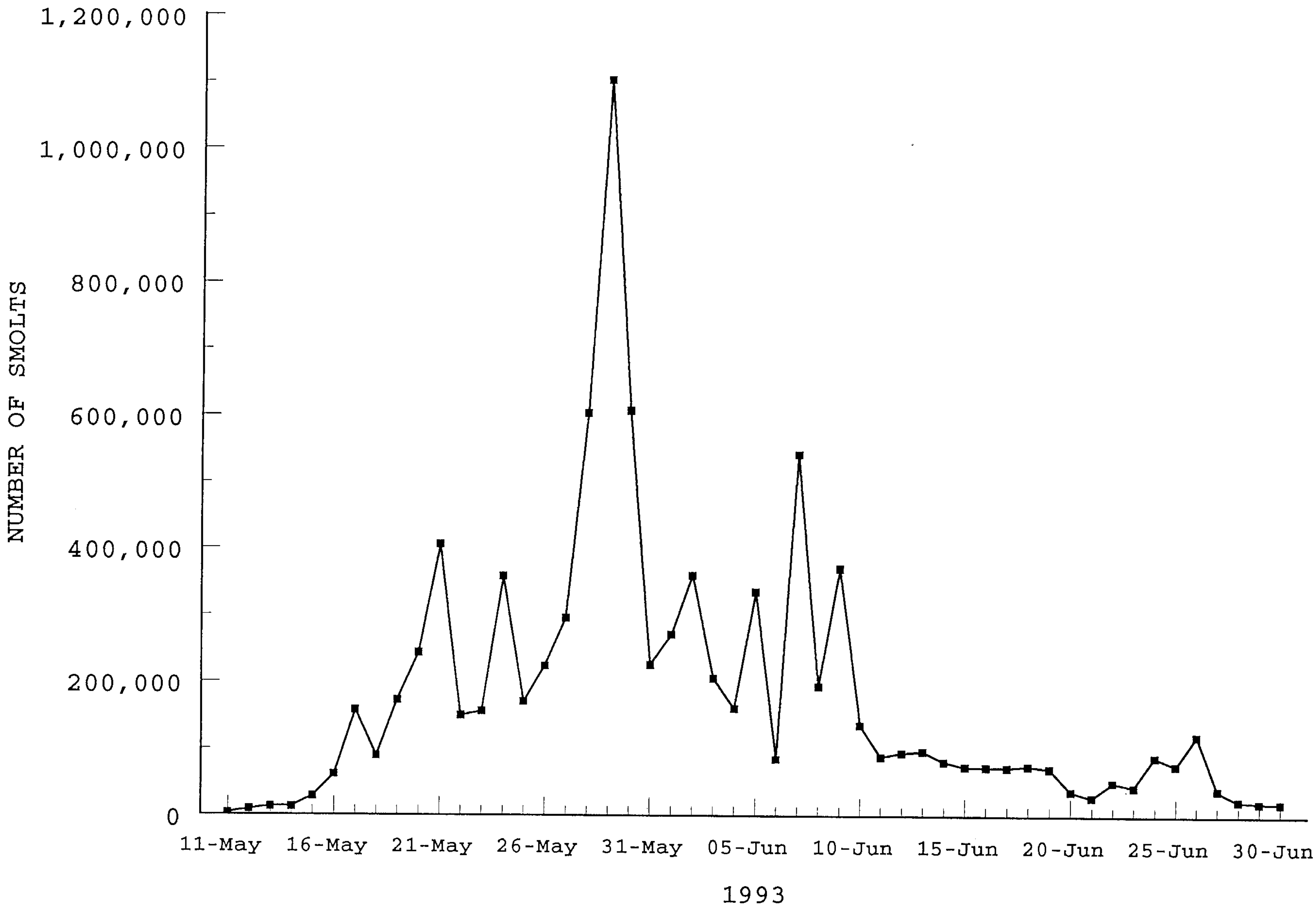

Figure 3. Migration timing for sockeye salmon smolts emigrating Tustumena Lake in 1993.